Discovery of the "Compton Shoulder" in the Iron Line from GX301–2

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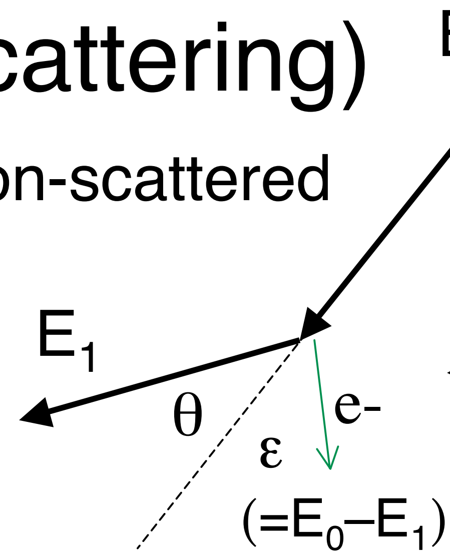
Introduction(Compton scattering)

When an X-ray photon (E_0) is Compton-scattered by an electron in a cold material,

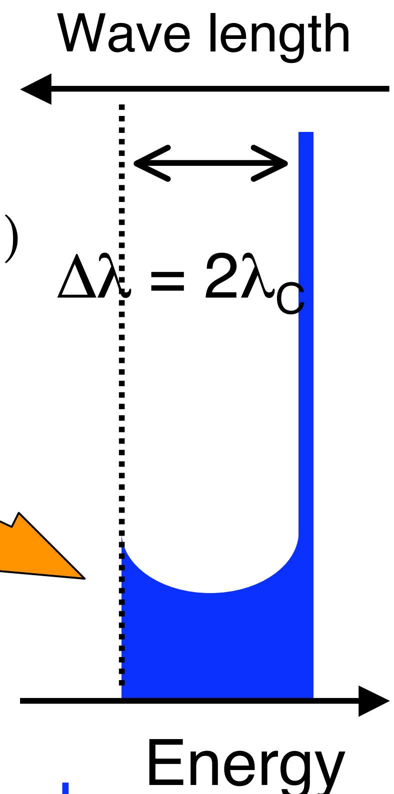
$$E_1 = \frac{E_0}{1 + E_0/mc^2\,(1-\cos\theta)}$$



If any X-ray emission lines are observed,

"Compton shoulder"

- the direct evidence of Compton scattering
- a probe for the physical states of the materials



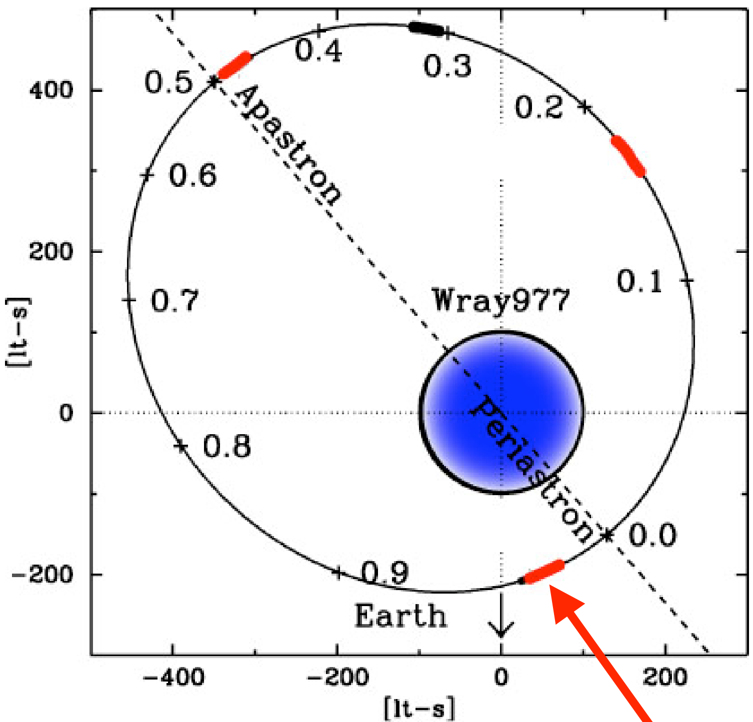
Observations with high energy resolution hold the key!

Iron Kα line(6.4keV) -> Compton shoulder: 6.24-6.40keV

width : 160eV

Chandra HETG is capable of detecting Compton shoulders

Observation of GX301–2 with Chandra HETG



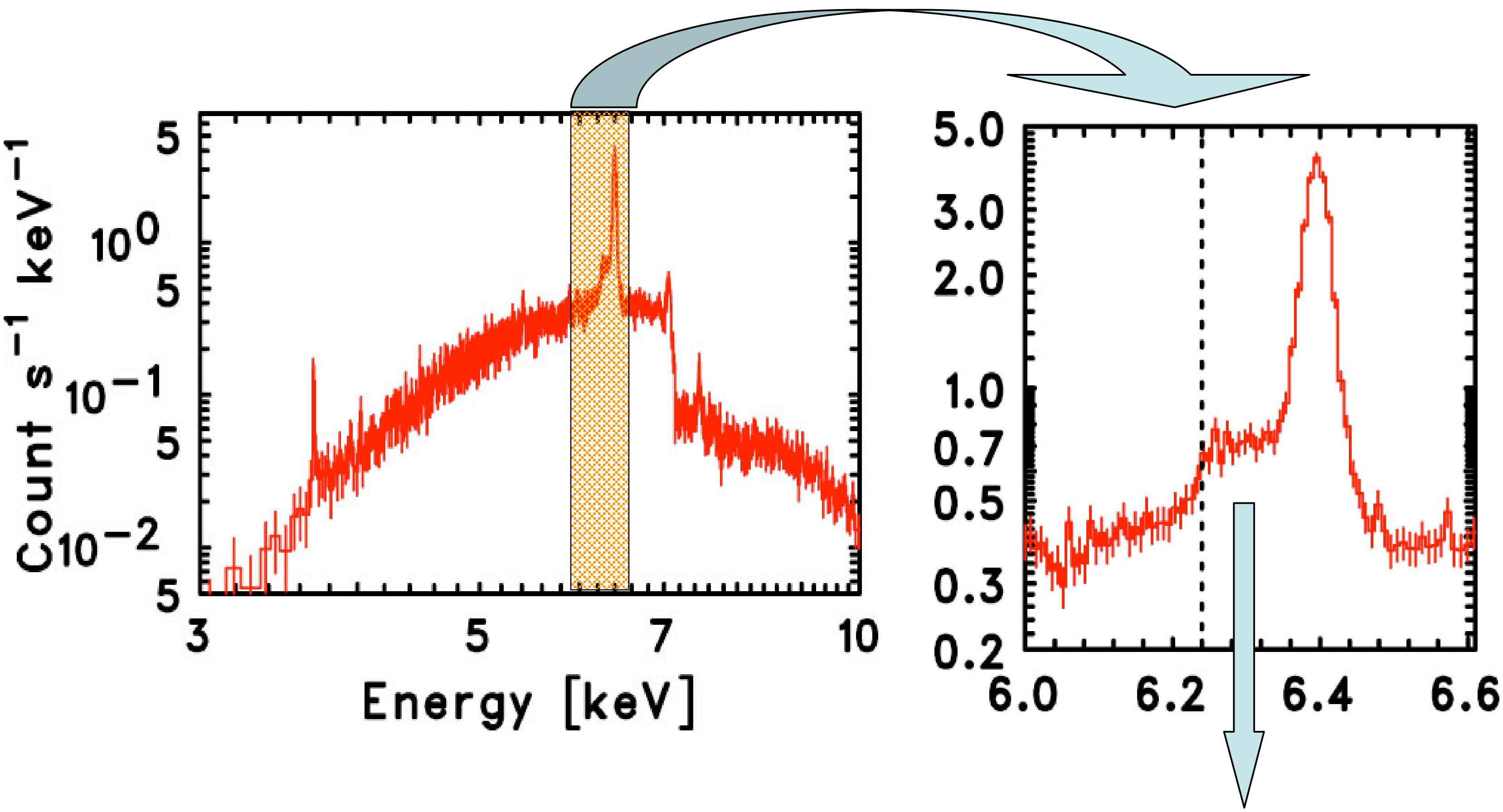
GX301–2

- High Mass X-ray Binary
  (NS and super-giant(B2Iae))
- Strong iron Kα line (EW ~ 1keV)
  –> the most promising target!!

We have observed at 3 orbital phases
(Intermediate(0.167-0.179) ~40ksec
Near-Apastron(0.480-0.497) ~60ksec
Pre-Periastron(0.970-0.982) ~40ksec)

Result of the observation

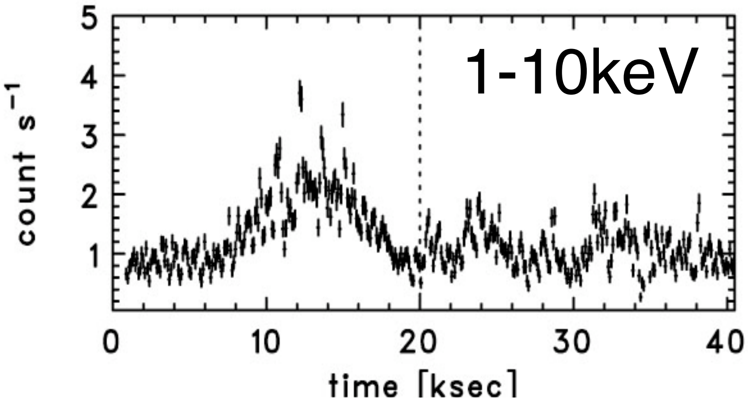
Energy spectrum from HEG ±1 order data



A "clear" Compton shoulder is detected for the first time!

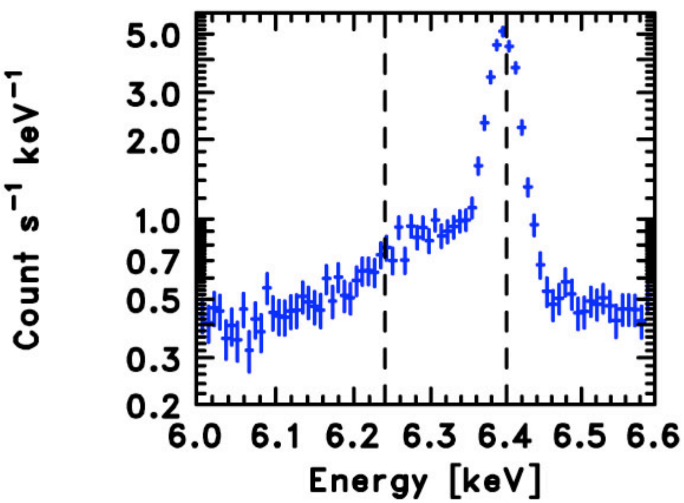
Variability of the Compton shoulder

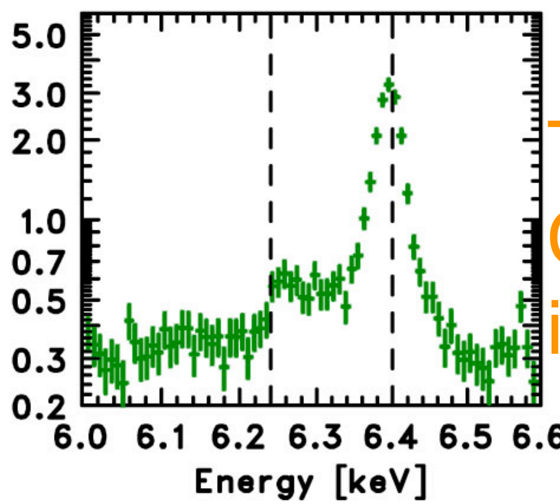
Light curve of HEG ±1 order



X-ray outburst is seen in the first half.

We divided the data into the first and second halves





The profile of the Compton shoulder is changed !

The first ~20 ksec The second ~20 ksec

How to reproduce the shoulder

Issues to be considered

- Two competing physical processes (photoelectric absorption and Compton scattering)
- Multiple scatterings

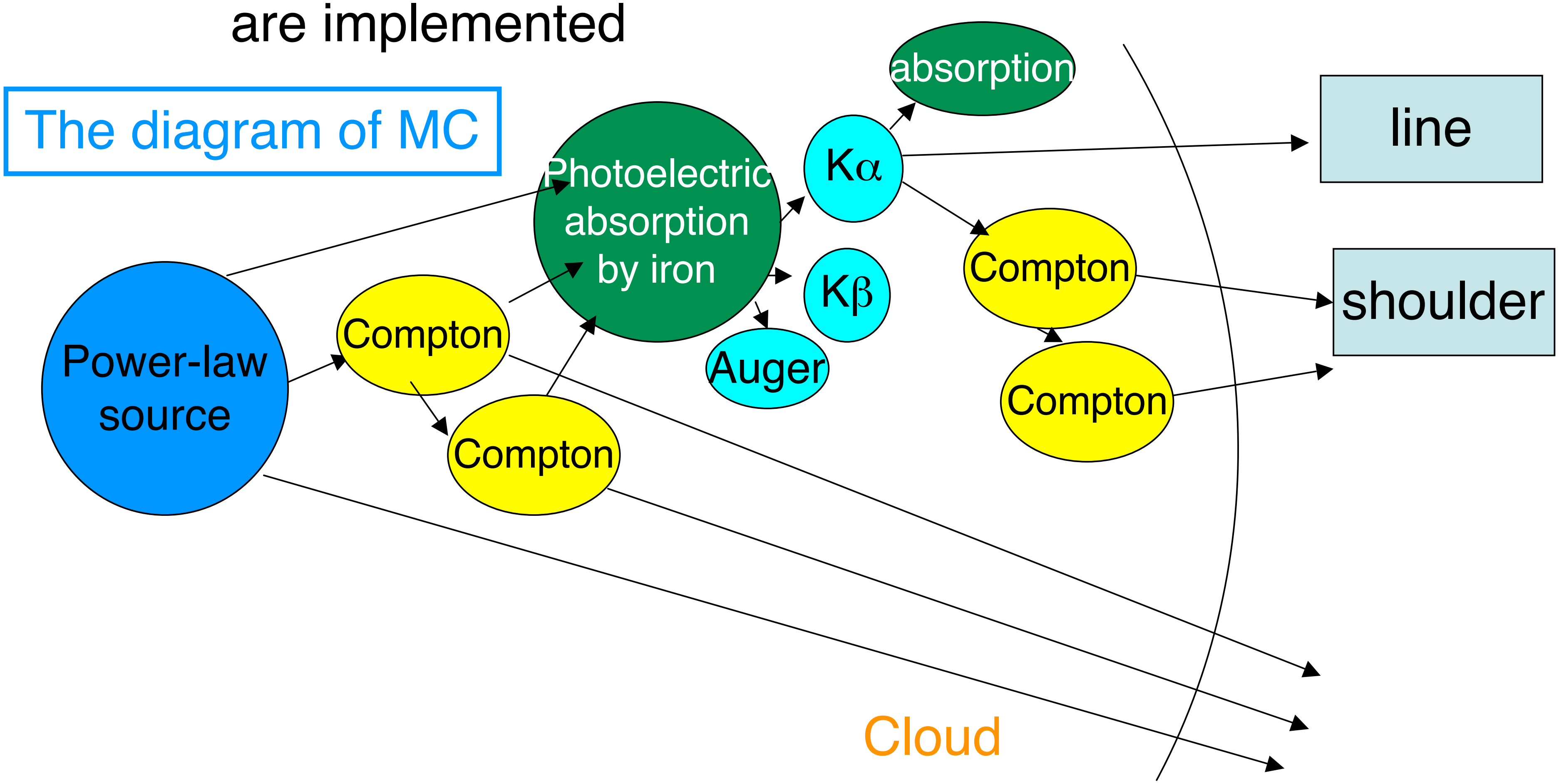
  $N_H \sim 10^{24} \mathrm{cm}^{-2}$ –> Optical depth of each process is ~1
- Geometry

It is too complex for analytical approaches.

The easiest way is the Monte Carlo simulation of photon transport.

The Monte Carlo simulation

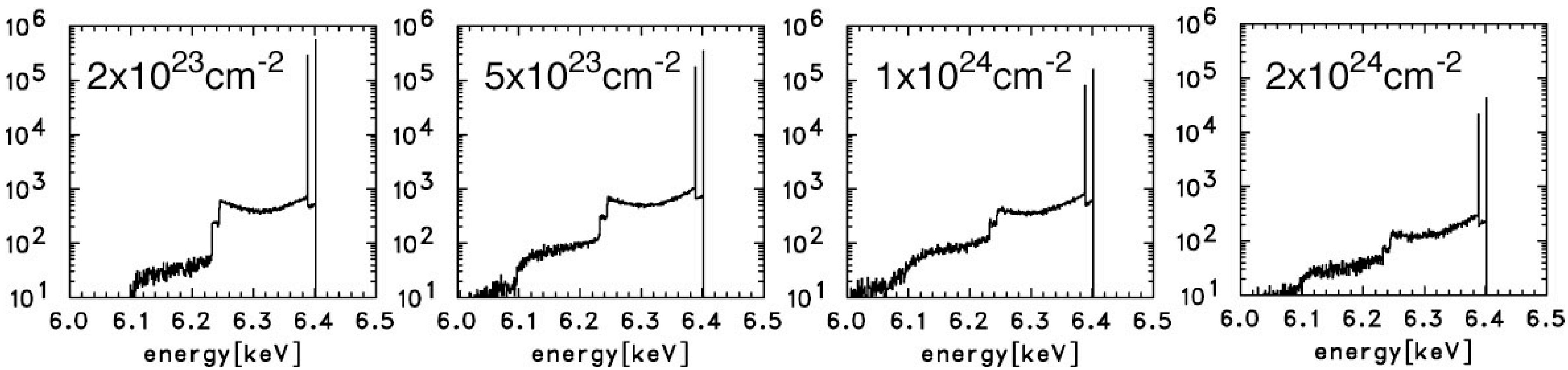
- A homogeneous spherical cloud
  - The NS (the power-law X-ray source) is located at the center
- Photoelectric absorption and Compton scattering are implemented

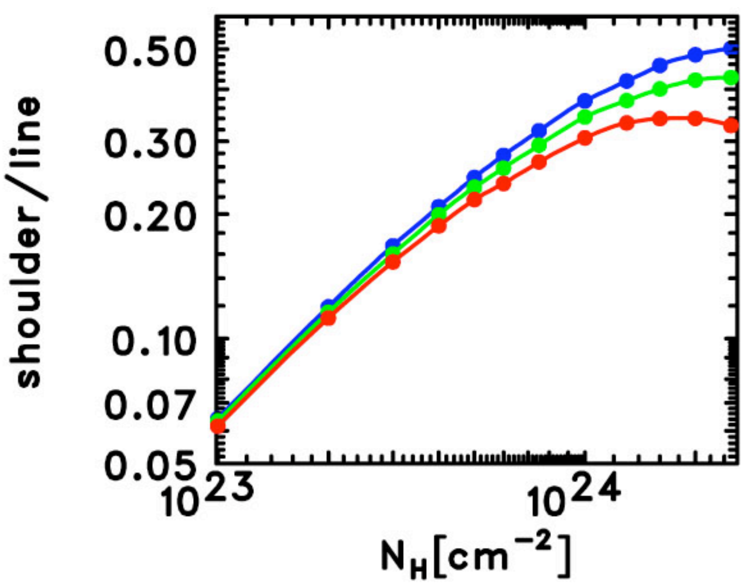


Results of Monte Carlo simulations(1)

A transition when N_H is changed. (kT_e is fixed 0eV)

(Metal Abundance: 0.7 cosmic)





The flux ratio of the shoulder to the line vs N_H

Metal abundance
for cosmic abundance(Feldman1992)

0.5 x cosmic

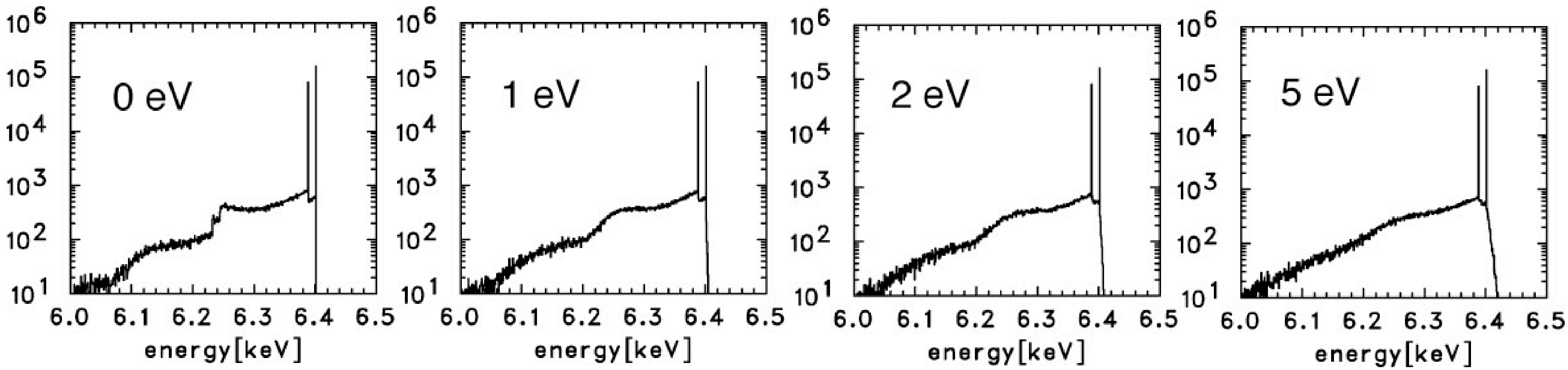
0.7 x cosmic

1.0 x cosmic

Results of Monte Carlo simulations(2)

A transition when kT_e is changed. (N_H is fixed 1×10^{24} cm^{-2})

(Metal Abundance: 0.7 cosmic)



The flux ratio of the shoulder to the line

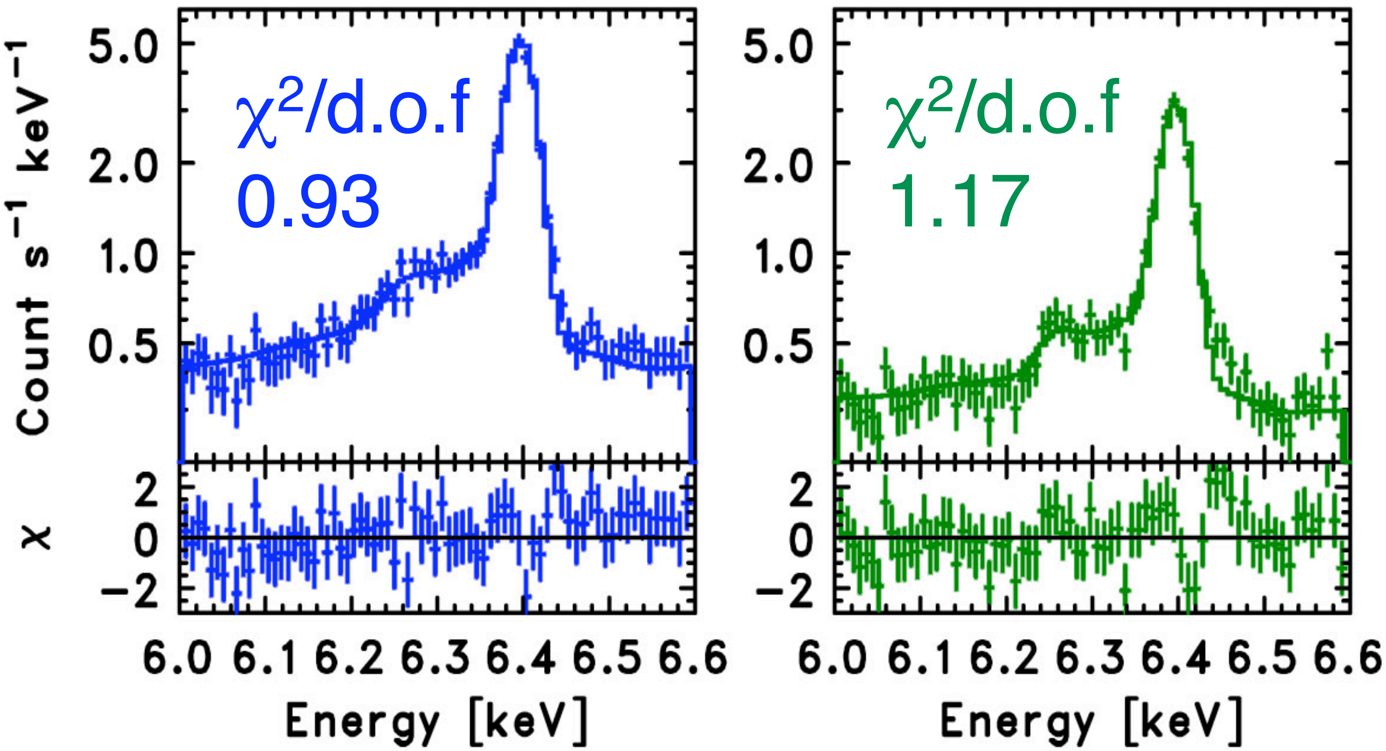
→ the optical depth and the abundance of the cloud

The shape of the shoulder

→ the temperature of scattering electrons

Fitting of the Compton shoulder

The first half The second half



0.7 cosmic abundance is adopted as the metal abundance

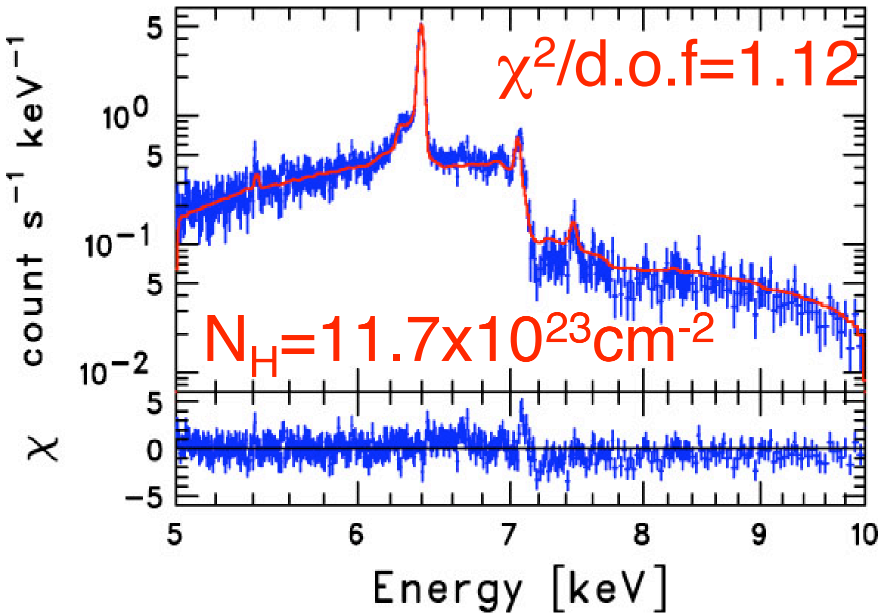
N_H 11.7+2.3/-2.0 x10^{23} cm^{-2}, 8.4±1.6 x10^{23} cm^{-2}

Upper limit of kTe < 3.7eV, <0.7eV (90%)

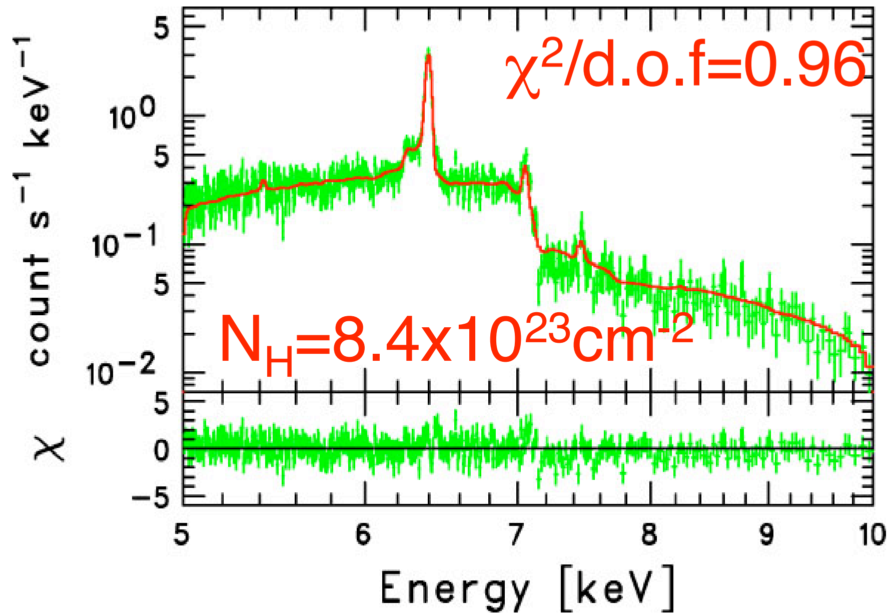
The new means for probing materials around X-ray sources!

N_H from the Compton shoulder can reproduce the whole spectrum shape

The first half



The second half



Full Monte Carlo simulation

- a spherical cloud
- a power-law source with Γ=1.0
- a metal abundance: 0.7 cosmic
- N_H derived from the Compton shoulder

We can obtain a self-consistent solution from the analysis of the Compton shoulder !

Summary

- We discovered the Compton shoulder in the iron Kα line of GX301–2
- From properties of the Compton shoulder, we have obtained physical parameters characterizing the material around the X-ray source, using Monte Carlo simulations.
- The new means for probing cold materials using Compton shoulders was established.

Future

ASTRO-E2 XRS

- Larger effective area(300cm^2@6keV)
  –> other X-ray binaries, AGNs
  diffuse sources (the Galactic center region)
- Excellent energy resolution (6eV@6keV)
  –> geometrical conditions